DOCUMENT RESUME

ED 463 954	SE 065 378
AUTHOR	Adams, April Dean; Griffard, Phyllis Baudoin
TITLE	Analysis of Alternative Conceptions in Physics and Biology: Similarities, Differences, and Implications for Conceptual Change.
PUB DATE	2001-03-28
NOTE	20p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (St. Louis, MO, March 25-28, 2001)
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Biology; Elementary Secondary Education; *Misconceptions; Physics; *Science Education
IDENTIFIERS	*Alternative Conceptions; *Conceptual Change

ABSTRACT

The purpose of this paper is to propose a matrix of attributes that characterize various alternative conceptions across the content areas, or domains, of science. It reports the results of testing the matrix on reported alternative conceptions by scoring their attributes and looking for trends in various domains. The authors found that some attributes seem to be more characteristic of alternative conceptions in physics and others to be more prevalent in the alternative conceptions in biology. These differences may correspond to the nature of the scientific knowledge within these respective domains of science. This matrix of attributes can be used to inform the development of instructional strategies that may remediate alternative conceptions. Identifying these attributes also helps to tease out the domain-specific learning challenges and better recognize the differences between the physical and life sciences with regard to the nature and structure of the scientific knowledge in those domains. (Contains 34 references.) (MM)

Analysis of Alternative Conceptions in Physics and Biology: Similarities, Differences, and Implications for Conceptual Change

A Paper Presented at the Annual Meeting of the
National Association for Research in Science Teaching
St. Louis, Missouri
March 28, 2001

Dr. April Dean Adams
Department of Engineering Physics and Physical Science
Northeastern State University
Tahlequah, Oklahoma 74464-2302
(918) 456-5511 ext. 3819
Adams001@cherokee.nsuok.edu

Dr. Phyllis Baudoin Griffard
Natural Sciences Department
University of Houston-Downtown
Houston, Texas 77002
(713) 221-8471
griffard@dt.uh.edu

Analysis of Alternative Conceptions in Physics and Biology: Similarities, Differences, and Implications for Conceptual Change

April Dean Adams, Northeastern State University and
Phyllis Baudoin Griffard, University of Houston-Downtown

Over two decades of research into alternative conceptions and conceptual change has led to numerous changes in recommendations for pedagogy, teacher education, and national standards. Science education research devoted to cognition and conceptual change has been productive in raising awareness of alternative conceptions and in developing teaching strategies which address them.

There are many levels at which educators have sought to understand and categorize student errors. Some have focused on categorizing the processing errors made by learners during assessment (Brown & van Lehn, 1979; Norman, 1981; Fisher & Lipson, 1986). This has helped educators better understand the real-time cognitive processing that occurs during learning. Another level of study has focused on the alternative conceptions that are purported to reside in the learners' conceptual frameworks to explain the *source* of the observed errors. It is at this level that much of the research on science learning has been conducted (Wandersee, Mintzes, & Novak, 1994). In an effort to generalize about student errors, several science educators have proposed categories, characteristics or criteria for the alternative conceptions they have studied. Dreyfus and Jungwirth (1989) proposed a synopsis of misconceptions in biology based on errors observed in questionnaire and interview responses. Their primary division is between conceptions in which pupils are personally involved, and those in which they are not. In the Introduction of *Cognitive Structure and Conceptual Change*, West and Pines (1985) also acknowledge two major sources of knowledge: that which is acquired from interacting with the environment, language and peers (in the Vygotskian sense), and formal instruction or school knowledge. Fisher and Lipson (1986) discuss the nature and sources of student errors, and recommend considering a learner's worldview, cognitive processing characteristics, mental/physical states, and aims or intentions when trying to explain a student error. White (1994) has argued that the results of research on alternative conceptions indicate a need for a theory of content. He suggests nine properties of content, including complexity and openness to common experience, that should be considered in designing instructional strategies. Many of these are also reflected in our analysis of the alternative conceptions literature.

The purpose of this paper is to propose a matrix of attributes that characterize various alternative conceptions across the content areas, or domains, of science. We also report the results of testing the matrix on reported alternative conceptions by scoring their attributes and looking for trends in various domains. We found that some attributes seem to be more characteristic of alternative conceptions in physics and others to be more prevalent in alternative conceptions in biology. These differences may correspond to the nature of the scientific knowledge within these respective domains of science. In the discussion we describe how this matrix of attributes can be used: to inform the development of instructional strategies that may remediate alternative conceptions. Identifying these attributes also helps to tease out the domain-specific learning challenges and better recognize the differences between the physical and life sciences with regard to the nature and structure of the scientific knowledge in those domains.

Research Questions

The following research questions were addressed in this study:

- Is there a *set of attributes* that alternative conceptions tend to share across disciplines, and if so what are they?
- What do these attributes suggest about the *instructional strategies* that might be most effective in changing specific alternative conceptions?
- What do these attributes suggest about the *level of difficulty* involved in remediating specific alternative conceptions?
- Does the strength or frequency of these attributes seem to be *different in the knowledge domains* of physics and biology?

Methods

The researchers are both university-based science educators with primary appointments in natural science departments. Both hold undergraduate and masters degrees in the sciences (ADA: Physics and Biology, PBG: Biochemistry) and doctorates in Science Education. Both have conducted research in cognition and conceptual change in secondary and/or post-secondary students (Adams, 1998a; Adams, 1998b) (Griffard, 1999; Griffard, 2000a; Griffard, 2000b). Having compared experiences with conceptual change, it was apparent that our outlooks with regard to alternative conceptions had been influenced by our pedagogical content knowledge in our respective teaching fields (physics and biology). Upon recognizing this contrast we set out to revisit the alternative conceptions literature with an eye toward identifying common attributes of reported alternative conceptions and comparing them across disciplines.

Phase One: The alternative conceptions literature is large. Therefore, we chose to begin by focusing on the alternative conceptions discussed in the often-cited review by Wandersee, Mintzes, and Novak (1994). We surveyed the original papers cited in the "representative findings in physics" and "representative findings in biology" sections of the review article, and focused on those alternative conceptions that tend to persist beyond adolescence. This decision was made because many of the reported alternative conceptions about biology in young children tend to be replaced by age 10 (Mintzes & Arnaudin, 1984; Carey, 1987). We determined that the recurring attributes should meet the following criteria: be useful across knowledge disciplines; account for the widespread nature of the alternative conceptions; account for individual differences in learner conceptions; indicate the level of difficulty in changing the learners' alternative conception, and indicate possible instructional strategies for conceptual change. During this phase, six reoccurring attributes emerged that appeared to meet these criteria.

Phase Two: A matrix was then devised that took the form of a rubric in which the attributes were listed along with sentences describing High, Medium and Low levels of each attribute. We selected representative studies cited in the review (Wandersee et al., 1994) and additional representative studies from other sources. The additional studies were necessary in order to provide a balanced view of the alternative conceptions literature, and in the case of biology, provide more examples alternative conceptions that persist into adolescence. Using this matrix, we scored two alternative conceptions in each of five major areas of physics (motion, force, light, nature of matter, and electricity) and two alternative conceptions in each of five major areas of biology (plant nutrition/photosynthesis, evolution, cellular respiration, circulation, and gas exchange). The physics alternative conceptions were described in papers by Trowbridge & McDermott (1981), McCloskey (1983), Clement (1982); Clement (1983); McDermott

(1984), Caramazza et al. (1980), Goldberg & McDermott (1986), Bouwens (1987), Novick & Nussbaum (1981), and Heller & Finley (1992). The biology alternative conceptions were described in papers by Brumby (1979), Fisher et al. (2000), Arnaudin & Mintzes (1985), Haslam & Treagust (1987), Dreyfus & Jungwirth (1989), Songer & Mintzes (1994), and Treagust & Mann (2000).

A significant challenge in the analysis of the selected biology topics was the distillation of a single alternative conception within each topic. As has been noted by Fisher (2000) and others, many alternative conceptions in biology are actually "constellations of alternative conceptions," or clusters of inter-related alternative conceptions that are directly related to the topic. For example, Fisher et al. (2000) identified 22 alternative conceptions in 12 clusters that contribute to the development and persistence of erroneous ideas about evolution. The other papers provided similar analyses. To deal with this incongruity across physics and biology for the purposes of this analysis, two representative alternative conceptions within each topic were selected as examples that typify problems with the topic. The caveat is that the stated alternative conceptions were examples provided by the researchers of a kind of erroneous idea that was witnessed in the course of the data collection, and are not necessarily widespread as stated. We chose to represent these in this way rather than a more vague statement such as "alternative energy sources" in order to anchor the alternative conception in a context for the reader.

The alternative conceptions identified in this way were then scored with respect to the attribute strengths. During this process an additional attribute emerged concerning language sensitivity and was added to the matrix.

Phase Three: After assigning the attribute strengths for the selected alternative conceptions, the researchers looked for patterns that might suggest effective instructional strategies, level of difficulty for conceptual change, and knowledge domain specificity. Several interesting patterns emerged that are discussed in the Findings.

Findings

The following seven attributes emerged during the course of the study: 1) *The Explanatory Power of the Alternative Conception in Everyday Situations; 2) The Interconnectedness of the Alternative Conception to Other Ideas or Concepts Held by the Learner*; 3) *The Accessibility to the Target Conception through Experiences; 4) Language Sensitivity of the Target Conception; 5) The Nature of the Representations Needed to Understand the Target Conception*; 6) *The Explanatory Power of the Target Conception in Everyday Situations*; and 7) *The Interconnectedness of the Target Conception to Other Ideas or Concepts Held by the Learner.* Note that the first two attributes concern the nature of the alternative conception held by the learner and the last five attributes concern the nature of the target conception which reflects current scientific understanding. Indicators of High, Medium, and Low relative strength are described in Table 1. A High score for attributes 1, 2, 4, and 5 seem to suggest greater difficulty will be encountered in changing the alternative conception, and a High score for attributes 3, 6, and 7 seem to suggest less difficulty.

Table 1
Attributes of Alternative and Target Conceptions and Indicators of their Relative Strength.

	Indicators of Relative Strength		
Attribute	Low (L)	Medium (M)	High (H)
1. *The Explanatory Power of the Alternative Conception in Everyday Situations*	The alternative conception is not elicited to explain everyday events.	The alternative conception is elicited to explain some everyday events.	The alternative conception is elicited to explain a variety of everyday events.
2. *The Interconnectedness of the Alternative Conception to Other Ideas or Concepts Held by the Learner*	There are no connections to other ideas or concepts.	There are few connections to other ideas or concepts.	There are many connections to other ideas or concepts.
3. *The Accessibility to the Target Conception through Experiences*	No experiences are possible, or complex explanations are needed in order to interpret the experience.	Experiences can demonstrate the target concept, but some explanations are needed.	Experiences can demonstrate the target concept with little or no explanation.
4. *Language Sensitivity of the Target Conception*	Terms are not context dependent or no redefinition of everyday terms is required.	Terms are somewhat context dependent or little redefinition of everyday terms is required.	Terms are greatly context dependent or redefinition of many everyday terms is required.
5. *The Nature of the Representations Needed to Understand the Target Conception*	No representations are needed, or they have a direct correspondence that is understood by most learners.	Representations have a correspondence that can be understood by most learners after explanation.	Representations are highly abstract, or require the learner to master many specific skills.
6. *The Explanatory Power of the Target Conception in Everyday Situations*	The target conception cannot be elicited to explain everyday events.	The target conception can be elicited to explain some everyday events.	The target conception can be elicited to explain a variety of everyday events
7. *The Interconnectedness of the Target Conception to Other Ideas or Concepts Held by the Learner*	There are no connections to other ideas or concepts.	There are few connections to other ideas or concepts.	There are many connections to other ideas or concepts.

White's exposition on the dimensions of content (White, 1994) were rediscovered late in this research. He proposed aspects of content that should be considered when teaching and correcting alternative conceptions. We recognized among these dimensions analogs to the attributes we describe, and therefore they provide triangulation of the findings of our inductive analysis (Table 2). He included other dimensions that had no analogs represented in the seven attributes, but which are certainly important in pedagogy. These dimensions were: *mix of types of knowledge, demonstrable versus arbitrary, social acceptance, and emotive power.*

Table 2
Analogous dimensions of content and attributes.

White's Dimensions of Content	Adams and Griffard's Attributes of ACs
• Openness to common experience	• Accessibility through experience
• Abstraction	• Need for representation
• Complexity	• Interconnectedness
• Presence of alternative models with explanatory power	• Explanatory power of conception in everyday situations
• Presence of common words	• Language sensitivity
• Extent of links	• Interconnectedness

Analysis of Alternative Conceptions in Biology: The alternative conceptions listed in Table 3 were analyzed with respect to the seven attributes identified in Phases One and Two. The analysis focused primarily on the exemplar alternative conception, rather than focussing on the "constellation" in which each resides. These assignments are subjective to the extent that the researcher's pedagogical content knowledge weighed heavily on the assignments. The analysis is summarized in Table 4. Five examples of rationales are offered to explain the process by which the assignments were made.

- The "Survival of the Strongest" AC was scored High for the attribute regarding the explanatory power of the AC in everyday situations because of the notion readily evokes the common human experience of competition, conflict, victory and defeat, which also have a high affective value.
- The "Plants feed on Soil Nutrients" AC was scored High for the attribute regarding the interconnectedness of TC to other ideas. All ACs except one was scored High with respect to this attribute. The highly propositional nature of biological nature, and the nested levels of organization at which this and the other phenomena can be explained, justified this designation.
- The "Smart Membranes" AC was the only one to be scored Medium (rather than Low) for the attribute regarding accessibility to the TC through experience because the phenomenon of osmosis is one relatively simple demonstration of the physical limitations of membrane permeability. Although this real-time experience can demonstrate that membranes are not "smart" but subject to the laws of physics, osmosis is but one feature of cell membrane selectivity encompassed by the AC.
- The "Only oxygen enters blood" AC was scored Medium for the attribute regarding the nature of representations needed. The notion that all gases in the air can enter the blood stream (including nitrogen, pollutants, and carbon

dioxide) by diffusion (partial pressure) in the same way that oxygen does can be conveyed readily with diagrams, provided that the learners are adept at decoding of graphics.

- The "Oxygen provides Energy" AC was scored Low for the attribute regarding the explanatory power of the TC in everyday situations because the role of oxygen as a final electron acceptor of the mitochondrial electron transport chain is rarely evoked for interpretation of everyday events. This will hinder meaningful encoding of this role.

Table 3
Summary of biology alternative conceptions analyzed in this study.

Topic	Alternative Conceptions	References
Evolution (EV)	1. AC: There is physical fighting among one species or different species, and the strongest win ("Survival of the strongest"). TC: Competition is indirect, and often for resource exploitation and health.	Fisher et al. (2000)
	2. AC: Changes in the environment induce mutations that adapt individuals to changed conditions ("Environment induces mutations"). TC: Mutations occur spontaneously and are necessary to introduce variation.	Brumby (1979)
Photosynthesis (PS)	1. AC: Plants receive most of their nutrition from the soil ("Plants feed on soil nutrients"). TC: Plants make sugar from CO2 and air and get only mineral nutrition and water from soil.	Wandersee (1986)
	2. AC: Photosynthesis occurs in plants; respiration occurs in animals ("Only animals respire"). TC: All organisms undergo cellular respiration.	Haslam & Treagust (1987)
Cellular Respiration (CR)	1. AC: Blood stream delivers only oxygen, not food (glucose, other nutrient molecules) to cells ("Blood delivers only O_2"). TC: Blood transports everything that diffuses into it, including food.	Songer & Mintzes (1994)
	2. AC: Oxygen is converted to energy in the process of respiration ("Oxygen provides energy"). TC: Oxygen is the final electron acceptor in the electron transport chain.	Treagust & Mann (2000)
Gas Exchange (GE)	1. AC: All air gets into the alveolus but the air is filtered by the alveolar wall so only oxygen gets into the blood ("Only oxygen enters blood"). TC: All gas molecules can cross the alveolus.	Treagust & Mann (2000)
	2. AC: Oxygen feeds muscles and organs with fresh air to relax them ("Oxygen relaxes muscles"). TC: Oxygen allows sufficient ATP production for working muscle.	Songer & Mintzes (1994)
Cellular Structure (CS)	1. AC: Some cells specialize in the making of proteins to be used by other cells ("Some cells make proteins for others"). TC: Cells specialize, but protein synthesis is carried out by all cells.	Dreyfus & Jungwirth (1989)
	2. AC: The cell "knows" what to allow across its membrane and will only let in things that are important ("Smart membranes"). TC: The phospholipid bilayer and its imbedded channels determine which molecules can cross.	Dreyfus & Jungwirth (1989)

AC = Alternative Conception
TC = Target Conception

Table 4
Analysis of attributes of biology alternative conceptions.

Attribute	Survival of the strongest EV1	Environment induces mutations EV2	Plants feed on soil nutrients PS1	Only animals respire PS2	Blood delivers only O_2 CR1	Oxygen provides energy CR2	Only oxygen enters blood GE1	Oxygen relaxes muscles GE2	Some cells make proteins for others CS1	Smart membranes CS2
1. Explanatory power of ACs in everyday situations	M	M	H	H	M	M	L	M	L	M
2. Interconnectedness of ACs to other ideas	H	M	H	H	M	M	M	M	L	M
3. Accessibility to TCs through experience	L	L	L	L	L	L	L	L	L	M
4. Language sensitivity of TCs	H	H	H	H	M	H	H	M	M	M
5. Nature of representations needed	H	H	H	H	H	H	M	M	M	H
6. Explanatory power of the TCs in everyday situations	L	L	L	L	M	L	L	L	L	L
7. Interconnectedness of TC to other ideas	H	H	H	H	H	H	H	H	M	H

AC = Alternative Conception
TC = Target Conception

Summary of findings regarding biology alternative conceptions and implications for instruction: Most of the biology alternative conceptions scored high with respect to interconnectedness of TC to other ideas, language sensitivity, and nature of representation needed. They also tended to score low with respect to accessibility to the TCs through direct experience and explanatory power of the TC in everyday situations. We acknowledge that it is possible that the purposive sampling of selected conceptions skewed the trends observed, and that other scientists and science educators may score these differently.

Interconnectedness. While all disciplines of science must be internally integrated, the life sciences are somewhat distinct from the others in this aspect. A justification for this distinction is that life can be studied at so very many levels of organization (molecular up to the biosphere). This creates a plethora of concept labels for the structures and processes operating at each level. Furthermore, explanations of life are dependent on and accountable to all the other laws of chemistry and physics, and therefore must consider them at all levels of this organization. Thus we argue that the interconnectedness attribute will be a major factor in conceptual change with respect to biology alternative conceptions. This aspect of interconnectedness is distinct from how this term applies to physics content, as discussed later.

Interconnectedness also accounts for the "constellation" problem in identifying biology alternative conceptions and the fact that learners seem to have idiosyncratic sets of erroneous ideas. It appears that no two students have the same profile of alternative conceptions for biology topics, causing researchers to categorize them or describe them rather than name them. One consequence of this is that there will be no "silver bullet" approach to conceptual change on these ideas. Rather, instruction will have to be designed such that prior knowledge is exposed in ways that reveal these small erroneous propositions in their framework. Once revealed to the teacher and recognized by the student, conceptual change is straightforward, and usually corrected by the learner herself. No sledgehammers are needed to hit these flies. A more fine-grained, "surgical strike" approach is warranted in these cases. The challenge is "dissecting" and isolating them in each learner's conceptual framework and raising the learner's awareness of them.

Dependence on language. Most biology alternative conceptions were scored high with respect to language dependence. It is likely that this attribute is directly related to the interconnectedness attribute because of the high number of interacting structures and processes studied in the life sciences. Each of these structures, processes and trends has been given a name, and these names change over time as understanding improves. Furthermore, since we have always been living things that interact with other living things, human language evolved to include many words relevant to biology long before the discipline existed. These words were naturally incorporated into the language of the discipline and eventually were used to describe very specific phenomena. This incongruence in use has been cited in numerous papers on alternative conceptions in biology and other content areas as well.

Nature of representations needed. Because of how inaccessible biology knowledge is through experience, as discussed below, biology teaching is rife with representations that must be decoded. There has been very little attention paid to how learners decode various representations that science education freely exploits. One type of representation is direct images in the form of photographs and micrographs that fail to convey scale and nestedness of the object in a larger context. Other images are drawings that frequently highlight significant features that would not be noticed by the occasional observer. More troublesome are images that are composites that are intended to relay the patterns but are rare or do not exist at all in nature as represented. Examples of these are the "typical animal cell" and the "typical flower anatomy." These images remove all cues to how much can be generalized about that concept to others, exacerbating any alternative conceptions that arise from over-generalization, such as the "Some cells make proteins for others" AC.

Another graphic representation biology education relies upon is the diagram, such as those used for life cycles and biochemical cycles, and those used to illustrate other relationships such as gas intake or output or food webs. These rely heavily on arrows whose meaning is rarely made clear to learners and on loops and circles whose entry and exit points are not usually explained. Also, these must necessarily include iconic examples (such as a single plant, or a single cell), and do not call the learner to evaluate exactly what these icons represent and which other organisms or cells could be substituted as easily. Other static diagrams of this type represent dynamic processes (such as electron transport) that perhaps are better served with animations. However, even animations do not offer enough context and cues to the learner to direct proper decoding of them (Griffard, 2000).

Another category of representations is the Cartesian graph, whose axes and grids are more likely to be familiar to most upper level science students. However there is little attention in science education to the issue of teaching graphic decoding of these representations within content areas; it has been left in the hands of the mathematics educators. Experience has shown that without prompting, students rarely will spontaneously commit cognitive resources to interpreting graphic data and trends in them. This has been recognized lately and has led to the inclusion of such graphic-heavy items on standardized tests at all levels.

Representations often exploited in biology that are staples in the domain of chemistry are the chemical equation, molecular formula, chemical structure and all the "shorthand" variations on their conventions. Because many biological processes necessarily rely on these representations in their explanations (e.g., in biogeochemical cycles, cellular

metabolism, macromolecular structures and assemblies, and gas exchange), students' ability to decode these representations in the context of biology is very important.

Explanatory power in everyday situations and access through experience. Biology alternative conceptions considered in this study generally scored medium and low for these attributes, respectively. Explanatory power was described at the outset to mean the readiness with which the conception (TC or AC) is evoked to explain everyday events. A conception with high explanatory power can more readily lead to a richer, more fruitful understanding of many situations. But powerful explanations in biology are highly integrated to subsume the numerous related structures, processes, and systems that are involved. Thus the explanatory power of isolated ACs and TCs in everyday situations seems to be less critical in the development of biology alternative conceptions because the isolated conception on its own is but a piece of the larger constellation of ideas. Without integration of the TC into the constellation, the explanatory power of the conception alone tends to be low, as indicated in the analysis.

This lack of explanatory power also seems to be related to the inaccessibility of the target conceptions through experience. Although the component pieces of biology topics have to have been accessible through experience in order to be researched by scientists, the explanations that are offered to make sense of these data are not accessible to direct experience except through extended and deep contact with data in these fields. This has been the approach of successful biology inquiry learning environments such as those of the BGuILE program (Reiser 1999). However, this in-depth approach with data is not practical for every biology topic, although this practicality/value tension is at the root of the mile wide/inch thick debate at the fore of the reform movement. Most biology courses will continue to attempt to teach these explanations in the absence of direct experience with data or phenomena.

It has been observed that children's erroneous ideas about biology seem to self-correct during childhood and during their science education. Even traditional curricula can help young learners refine their definitions of life and animals, and their understanding of the role of body parts or blood. Perhaps it is the accessibility of these phenomena through experience that makes these alternative conceptions more amenable to change and less troublesome to us as science educators.

Analysis of Alternative Conceptions in Physics: The alternative conceptions listed in Table 5 were analyzed with respect to the seven attributes identified during Phase One and Phase Two. The division between Motion AC and Force AC is somewhat arbitrary due to the close relationship between force and motion concepts. However, the AC literature is so large in mechanics that it seemed wise to include an analysis of more than two ACs. In addition, assignment of the strength of the attribute was complicated by the interconnectedness of the fundamental ideas in physics. This analysis stayed very close to the concept as stated. It could be argued for instance that differentiating between velocity and acceleration is not totally understood until the learner can correctly interpret position versus time graphs and velocity versus time graphs. This kind of extended understanding was not addressed here. The analysis is summarized in Table 6. Five examples of rationales are offered to explain the process by which the assignments were made.

- The "Velocity and Acceleration" AC scored High in the nature of representations needed because differentiating between velocity and acceleration requires a qualitative and quantitative understanding of the

mathematical representations: velocity equals the change in position divided by the change in time ($v = \Delta d/\Delta t$); and acceleration equals the change in velocity divided by the change in time ($a = \Delta v/\Delta t$). This AC also scored High in explanatory power of the TC in everyday situations because a correct understanding of the difference velocity and acceleration can be useful to explain many everyday aspects of motion such as running, driving a car, or playing sports.

- The "Motion implies force" AC scored High in the explanatory power of the AC in everyday situations because this AC is useful in explaining everyday occurrences in a frictional world, such as a ball rolling to stop if a force is not continually applied. However, this AC also rated High in the explanatory power of the TC because a full understanding of the relationship between force and motion can also be used to explain the same everyday occurrences in a more satisfying manner. It may seem contradictory that this AC also scored Low in accessibility of the TC through experience. However, direct experience with the TC would require frictionless surfaces that can only be imagined or simulated.
- The "Plane mirror, image size" AC scored Low in the explanatory power of the AC because although students have observed that moving back from a mirror results in them seeing more of themselves (due to the fact that the mirror and floor are not plumb), they really do not use this concept to explain images produced by mirrors. However, it was rated High in interconnectedness of AC to other ideas because this observation can be used to predict how to stand in front of a mirror, a common everyday occurrence.
- The "Heat, expansion of particles" AC scored High in interconnectedness of TC to other ideas because the concept that when gas particles are heated, they have more energy and move faster is such a fundamental idea about the nature of matter and the understanding of heat, energy, and temperature concepts.
- The "Current same for all circuits" AC scored high in the nature of representations needed because of the importance of the interpretation of schematic diagrams in fully understanding the TC.

Table 5

Summary of physics alternative conceptions analyzed in this study.

Topic	Alternative Conceptions	References
Motion (M)	1. AC: The concepts of velocity and acceleration are not clearly differentiated. ("Velocity and acceleration") TC: Acceleration is the change in velocity divided by the time interval over which it occurred. Velocity is the change in position divided by the time interval over which it occurred.	Trowbridge & McDermott (1981)
	2. AC: Curvilinear motion continues after a ball emerges from a circular track. ("Curvilinear motion") TC: A ball emerging from a circular track will move in a straight line that is tangent to the track.	McCloskey (1983); Caramazza et al. (1980)
Force (F)	1. AC: A force is required for motion to continue. ("Motion implies force") TC: An object in motion will continue at a constant speed in a straight line unless a net force is applied.	Clement (1982); Clement (1983); McDermott (1984)

	2.	AC: Under the influence of a constant force, objects move with constant velocity. ("Constant force, constant velocity") TC: Under the influence of a constant net force, objects will move with constant acceleration.	Clement (1983)
Light (L)	1.	AC: Moving farther from a plane mirror will enable someone to see more of their body in the image. ("Plane mirror, image size") TC: If you move farther away from a plane mirror you will still see the same amount of your body in the image.	Goldberg & McDermott (1986)
	2.	AC: It is not necessary for light to enter the eye in order for an object to be seen. ("Vision without light entering eye") TC: An object can be seen when light strikes the object and then is reflected to the eye.	Bouwens (1987)
Nature of Matter (NM)	1.	AC: There is vapor or oxygen between gas particles. ("Space between particles filled") TC: There is empty space between gas particles.	Novick & Nussbaum (1981)
	2.	AC: Heating gas particles causes the particles to expand, or the particles are forced apart. ("Heat, expansion of particles") TC: When gas particles are heated, they have more energy and move faster.	Novick & Nussbaum (1981)
Electric Circuits (EC)	1.	AC: A battery releases the same, fixed amount of current to every circuit. ("Current same for all circuits") TC: For a particular battery, current flow in a circuit depends on the electrical resistance in the circuit.	Heller & Finley (1992)
	2.	AC: When there is more than one bulb in a circuit, each bulb uses up some of the current so that each bulb receives less current. ("Current used up") TC: The bulbs share the voltage. The current is the same everywhere in a DC circuit.	Heller & Finley (1992)

AC = Alternative Conception
TC = Target Conception

Table 6
Analysis of attributes of physics alternative conceptions.

	Velocity and acceleration	Curvilinear motion	Motion implies force	Constant force, constant velocity	Plane mirror image size	Vision without light entering eye	Space between particles filled	Heat, expansion of particles	Current same for all circuits	Current used up
Attribute	M1	M2	F1	F2	L1	L2	NM1	NM2	EC1	EC2
1. Explanatory power of ACs in everyday situations	L	L	H	H	L	H	L	M	M	L
2. Interconnectedness of ACs to other ideas	M	L	H	H	H	H	M	M	M	M
3. Accessibility to TCs through experience	M	H	L	M	M	L	L	L	M	M
4. Language sensitivity of TCs	M	M	M	M	L	L	M	M	M	M
5. Nature of representations needed	H	M	M	H	M	M	H	H	H	H
6. Explanatory power of the TCs in everyday situations	H	H	H	H	M	M	L	M	M	M
7. Interconnectedness of TC to other ideas	H	H	H	H	M	H	M	H	H	H

AC = Alternative Conception
TC = Target Conception

Summary of findings regarding physics alternative conceptions and implications for instruction. Most of the physics alternative conceptions scored High with respect to interconnectedness of the TC to other ideas and to the nature of representation needed. There were a variety of scores for the accessibility of the TC to experiences. In addition,

all of the mechanics ACs scored High in explanatory power of the TC in everyday situations. Unfortunately the explanatory power of the ACs is also High for force concepts. In contrast, no ACs scored High in language sensitivity. Usually in physics, the TC's language sensitivity involves the use of everyday words that have a slightly different meaning in physics.

Interconnectedness. The interconnectedness of concepts in physics results from the reduction of complex situations to fundamental ideas that can be used to analyze them. This seems to occur across physics content areas. Therefore the interconnectedness of concepts is due to this reduction and not to the complexity of interactions among concepts, as it seems to be in biology. It seems apparent that focusing on fundamental ideas in physics such as, force, energy, heat, and motion would be useful in conceptual change across a wide range of physics content areas. Therefore, instruction should emphasize these connections and ensure that students are applying them consistently with good understanding.

Nature of representations needed. In physics, representations are commonly mathematical, graphical, or symbolic. Mathematical representations typically show relationships between variables and are often used to define concepts. Understanding the implications of mathematical relationships on physical situations is often problematic for learners. Similarly, Cartesian graphs are another useful method of showing relationships between concepts and predicting what will occur in physical situations, but it has been shown that interpreting graphs in this way can be difficult for learners even though this is a fundamental skill. Symbolic representations include schematic diagrams of electrical circuits, free body diagrams in mechanics, and ray diagrams commonly used in optics. The symbols used in these representations have highly specialized meanings that are often misinterpreted by learners. TCs that have a high dependence on representations will require instruction that is directed toward both explaining the meaning of the representations and giving the learner opportunities to use the representation to explain or to predict physical events. Establishing the connection between the representation and physical events is essential for a full understanding of conceptions in physics.

Accessibility of TC to experience. The scoring for this attribute varied from AC to AC. Medium and Low scores were given for three basic reasons, 1) the experience relied on measurements mediated by equipment instead of direct observation or measurement, for example ammeters to measure current, 2) the experience could not be directly interpreted without taking into account the force of friction, or 3) there was no direct experience available due to scale, for example motion of particles at the atomic scale. This attribute suggests that assumptions underlying measurements and the application of concepts to experiences must be explicitly stated and emphasized if learners are to benefit from physics demonstrations and laboratory experiences.

Explanatory power of the TC. Target conceptions in mechanics tend to have great explanatory power in everyday situations. This attribute should facilitate the understanding of concepts. However, often their explanatory power is short circuited because physics is only primarily taught in the ideal world where friction does not exist. This may result in students deciding that physics is not useful in the real world (Adams, 1998a), or, in other words, that physics is only useful in the classroom, or useful to physicists. This conclusion is ironic because in fact physics is extremely useful in everyday situations. Students will not be able to see this however as long as examples and applications of physics concepts are relegated to ideal situations.

Explanatory power of the AC and connections to other ideas. Perhaps another reason that the explanatory power of the target conception concerning forces is not always clear to learners is that commonly held alternative conceptions also have great explanatory power in everyday situations. These alternative conceptions have been developed over time by the learner and are used to predict and explain a diverse set of experiences such as the behavior of a tossed ball, the rules of driving on a frictional surface, and the motion of objects as they fall to the ground. This everyday usefulness of commonly held ideas about forces sets up a competition between the alternative conception and the targeted conception. Some students resolve this competition by only using the targeted concept in school situations and relying on the alternative conception in everyday situations (Adams, 1998a). This analysis reemphasizes the importance of reconciling physics concepts, which are taught in the ideal, to everyday situations. Otherwise, learners will isolate the target conception and continue to cling to their alternative conception.

Comparing the Attributes of Alternative Conceptions in Biology and Physics: The scores for the alternative conceptions in biology and physics are shown in Table 7. Sweeping generalizations about the differences in attributes between alternative conceptions in biology and physics are not possible because of the small sample of alternative conceptions analyzed here. However, at least within this sampling, the alternative conceptions in biology appear to be more language dependent than physics alternative conceptions. In addition, the interconnectedness of many diverse biology ideas in one constellation seems distinct from the nature of interconnectedness in physics. This language dependence and interconnectedness may be the reason that concept mapping is seen as such an important tool in biology, but seems to be less useful in understanding physics. This difference is consistent with what is known about the highly integrated, propositional nature of biological knowledge that can be studied at many levels of organization (Mayr, 1982). In contrast, physics attempts to reduce complex situations to a relatively small number of fundamental quantities and relationships in order to facilitate analysis. This is not to say that concept maps are useless in physics, but rather that they are more valuable in biology where the number of specialized terms, concepts, and relationships are more complex and hierarchical.

Another tentative conclusion from this comparison is that the target conceptions in physics have more explanatory power in everyday situations than do the target conceptions in biology. This explanatory usefulness should facilitate understanding except that in many examples where the explanatory power of the TC is High, the explanatory power of the AC also scored High. As discussed previously, this seems to set up a competition between conceptions that can result in the isolation of physics knowledge from everyday situations.

Biology has a different problem with explanatory power. Neither the biology AC nor TC has much explanatory power in everyday situations. Therefore, how can the content be made meaningful except in the context of other biology content? This difference in explanatory power between physics and biology may explain why the four-step process advocated by Posner et al. (1982) seems to be more appropriate for conceptual change in physics than in biology.

Differences in explanatory power also support the idea that naïve theory building may not be as an important source of alternative conceptions in biology as it is in physics. It has been argued that an alternative conception about cellular metabolism is not accessible to experience in everyday life and therefore could not have arisen from naïve

theories (Lawson 1988). Rather, alternative conceptions of this type seem to arise from a mismanipulation of facts learned in the classroom. One type of mismanipulation occurs when a learner spontaneously forms inappropriate links between concepts when he confronts a gap in his knowledge (Griffard, 2000). Another example is over-generalizing one situation to others, as in the "Some cells build proteins for others" misconception (Jungwirth and Dreyfus). One could argue that gap-bridging is a type of naïve theory-building on a micro-scale, and is as much a source of alternative conceptions as childhood theories about force and motion.

Table 7

Comparison of attribute scores for alternative conceptions in biology and physics.

	Biology			Physics		
Attribute	Number of Ratings			Number of Ratings		
	High	Medium	Low	High	Medium	Low
1. Explanatory power of ACs in everyday situations	2	6	2	3	2	5
2. Interconnectedness of ACs to other ideas	3	6	1	4	5	1
3. Accessibility to TCs through experience	0	1	9	1	5	4
4. Language sensitivity of TCs	6	4	0	0	8	2
5. Nature of representations needed	7	3	0	6	4	0
6. Explanatory power of the TCs in everyday situations	0	1	9	4	5	1
7. Interconnectedness of TC to other ideas	9	1	0	8	2	0

AC = Alternative Conception
TC = Target Conception

Summary

In this study, seven attributes of alternative and target conceptions were identified that may be useful in analyzing alternative conceptions across science disciplines. Ten alternative conceptions in biology and ten alternative conceptions in physics were then assigned indicators of High, Medium, or Low strength based upon descriptors. A comparison of the results for biology and physics alternative conceptions indicate that:

- The biology alternative conceptions tend to be more language sensitive than the physics alternative conceptions.
- The target conceptions in physics have more explanatory power in everyday situations than do the target conceptions in biology.
- In some physics content areas the alternative conceptions and target conceptions both have high explanatory power in everyday situations that may result in competition.
- In some biology content areas neither the alternative conception nor the target conception has explanatory power in everyday situations.
- Interconnectedness plays important roles in physics and biology TCs but in distinct ways.

Furthermore, the variety in scores even within the same content discipline indicates that different alternative conceptions give students difficulty for different reasons. This indicates that instructional strategies need to address these differences and that attempts to find one conceptual change model that will be successful for all alternative conceptions will not be successful. Instead, we are suggesting that instructional decisions be based on the attributes that seem to be most influential for a

particular alternative conception. The next phase of this research will focus on the following questions:

- Are the indicators used to determine the strength of an attribute clear enough so that different educational researchers assign similar scores to specific alternative conceptions?
- Will expanding our analysis to additional alternative conceptions in biology and physics and to different science content areas result in additional attributes?
- Do the instructional strategies recommended by the attributes of a particular alternative conception facilitate the learning of the target conception?

The last question is perhaps the most important because it will determine the usefulness of this research in the classroom.

References

Adams, A. D. (1998a). *Students' beliefs, attitudes and conceptual change in a traditional high school physics classroom*. Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA.

Adams, A. D. (1998b). *Students' beliefs, attitudes, and conceptual change in a traditional high school physics classroom.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Arnaudin, M. W. & J. J. Mintzes (1985). Students' alternative conceptions of the human circulatory system: A cross-age study. *Science Education 69*(5): 721-733.

Bouwens, E. A. (1987). In J. D. Novak (Ed.) *Proceedings of the second international seminar on misconceptions and educational strategies in science and mathematics*. (Vol.III, pp.97-107) Ithaca, NY: Department of Education, Cornell University.

Brown, J. S. & van Lehn, K. (1979). Repair theory: A generative theory of bugs in procedural skills. *Cognitive Science 4*: 379-426.

Brumby, M. (1979). Problems in learning the concept of natural selection. *Journal of Biological Education 13(*2): 119-122.

Carey, S. (1987). *Conceptual Change in Childhood.* Cambridge, MIT Press.

Caramazza, A. McCloskey, M. & Green, B. (1980). Curvilinear motion in the absence of external forces: Naïve beliefs about the motion of objects. *Science, 210*, 1139-1141.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics 50*(1): 66-70.

Clement, J. (1983). A conceptual model discussed by Galileo and used intuitively by physics students. In D. Gentner & A. Stevens (Eds.), *Mental models*, (pp. 325-339). Hillsdale, NJ: Lawrence Erlbaum.

Dreyfus, A. & Jungwirth, E. (1989). The pupil and the living cell: A taxonomy of dysfunctional ideas about an abstract idea. *Journal of Biological Education 23*(1): 49-55.

Fisher, K., D. Anderson, et al. (2000). *Evolution as an experimental science: Implications for developing and assessing students' conceptions*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Fisher, K. & Lipson, J. I. (1986). Twenty questions about student errors. *Journal of Research in Science Teaching 23*(9): 783-803.

Goldberg, F. & McDermott, L. (1986). Student difficulties in understanding image formation by a plane mirror. *Physics Teacher, 24*, 472-480.

Griffard, P. B. (1999). *Exposing gaps in college biochemistry understanding using new cognitive probes*. National Association for Research in Science Teaching, Boston, MA.

Griffard, P. B. (2000a). *Evidence of college students' graphic decoding gaps during use of a computer simulation of photosynthesis*. Mathematics/Science Education and Technology, San Diego, CA.

Griffard, P. B. (2000b). *Toward a comprehensive typology of gaps in college biology students' understanding of photosynthesis*. National Association for Research in Science Teaching, New Orleans, LA.

Haslam, F. & Treagust, D. F. (1987). Diagnosing secondary students' misconceptions about photosynthesis and respiration in plants using a two-tier multiple choice instrument. *Journal of Biological Education 21*(3): 203-211.

Heller, P. M. & Finley, F. N. (1992). Variable uses of alternative conceptions: A case study in current electricity. *Journal of Research in Science Teaching 29*(3): 259-275.

Lawson, A. E. (1988). "The acquisition of biological knowledge during childhood: Cognitive conflict or tabula rasa?" *Journal of Research in Science Teaching* **25**(3): 185-199.

Mayr, E. (1982). *The Growth of Biological Knowledge*. Cambridge, Harvard University Press.

McCloskey, M. (1983). Naïve theories of motion. In D. Gentner & A. Stevens (Eds.), *Mental models* (pp. 299-324). Hillsdale, NJ: Lawrence Erlbaum.

McDermott, L. (1984). Research on conceptual understanding in mechanics. *Physics Today, 37*, 24-32.

Mintzes, J. J. & Arnaudin, M.W. (1984). Children's biology: A review of research on conceptual development in the life sciences. *ERIC document ED 249 044*.

Norman, D. A. (1981). Categorization of action slips. *Psychological Review 88*(1): 1-15.

Novick, S. & Nussbaum, J. (1981). Pupils' understanding of the particulate nature of matter: A cross-age study. *Science Education, 65*, 187-196.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a science conception: Toward a theory of conceptual change. *Science Education, 66*, 211-227.

Reiser, B. (1999). The Galapagos Finches. Evanston, IL.

Songer, C. J. & Mintzes, J. J. (1994). Understanding cellular respiration: An analysis of conceptual change in college biology. *Journal of Research in Science Teaching 31*(6): 621-637.

Treagust, D. & Mann, M. (2000). *An instrument to diagnose students' conceptions of breathing, gas exchange, and respiration.* National Association for Research in Science Teaching, New Orleans, LA.

Trowbridge, D. E. & McDermott, L. (1981). Investigation of student understanding of the concept of acceleration in one dimension. *American Journal of Physics, 48*, 242-253.

Wandersee, J. H., Mintzes J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. *The handbook of research in science teaching and learning*. D. Gabel. New York, MacMillan: 177-210.

West, L. H. T. and A. L. Pines (1985). Introduction. *Cognitive structure and conceptual change.* L. H. T. West and A. L. Pines. Orlando, Academic Press.

White, R. T. (1994). Dimensions of Content. *The content of science: A constructivist approach to its teaching and learning.* P. Fensham, R. Gunstone and R. White. Washington, D.C., The Falmer Press.

U.S. Department of Education

Office of Educational Research and Improvement (OERI)

National Library of Education (NLE)

Educational Resources Information Center (ERIC)

Reproduction Release

(Specific Document)

I. DOCUMENT IDENTIFICATION:

Paper Presented at the Annual Meeting of the National Association for Research in Science Teaching, St. Louis, Missouri, March 28, 2001

Title: Analysis of Alternative Conceptions in Physics and Biology: Similarities, Differences, and Implications for Conceptual Change

Author(s): Dr. April Dean Adams and Dr. Phyllis Baudoin Griffard

Corporate Source: Publication Date:

II. REPRODUCTION RELEASE:

In order to disseminate as widely as possible timely and significant materials of interest to the educational community, documents announced in the monthly abstract journal of the ERIC system, Resources in Education (RIE), are usually made available to users in microfiche, reproduced paper copy, and electronic media, and sold through the ERIC Document Reproduction Service (EDRS). Credit is given to the source of each document, and, if reproduction release is granted, one of the following notices is affixed to the document.

If permission is granted to reproduce and disseminate the identified document, please CHECK ONE of the following three options and sign in the indicated space following.

{ HTMLCONTROL Forms.HTML:Text.1 }Check here for Level 1 release, permitting reproduction and dissemination in microfiche or other ERIC archival media (e.g. electronic) and paper copy.

{ HTMLCONTROL Forms.HTML:Text.1 }Check here for Level 2A release, permitting reproduction and dissemination in microfiche and in electronic media for ERIC archival collection subscribers only .

{ HTMLCONTROL Forms.HTML:Text.1 }Check here for Level 2B release, permitting reproduction and dissemination in ERIC archival collection microfiche only.

Documents will be processed as indicated provided reproduction quality permits. If permission to reproduce is granted, but no box is checked, documents will be processed at Level 1.

I hereby grant to the Educational Resources Information Center (ERIC) nonexclusive permission to reproduce and disseminate this document as indicated above. Reproduction from the ERIC microfiche, or electronic media by persons other than ERIC employees and its system contractors requires permission from the copyright holder. Exception is made for non-profit reproduction by libraries and other service agencies to satisfy information needs of educators in response to discrete inquiries.

Signature: Printed Name/Position/Title:

April Dean Adams

April Dean Adams

Assistant Professor of Science Education

Organization/Address: Telephone: Fax:

Northeastern State University

College of Math, Science, and Nursing

611 N. Grand

Tahlequah, OK 74464-2302

E-mail Address: adams001@nsuok.edu

Date: November 30, 2001

III. DOCUMENT AVAILABILITY INFORMATION (FROM NON-ERIC SOURCE):

If permission to reproduce is not granted to ERIC, or, if you wish ERIC to cite the availability of the document from another source, please provide the following information regarding the availability of the document. (ERIC will not announce a document unless it is publicly available, and a dependable source can be specified. Contributors should also be aware that ERIC selection criteria are significantly more stringent for documents that cannot be made available through EDRS.)

Publisher/Distributor:

Address:

Price:

IV. REFERRAL OF ERIC TO COPYRIGHT/REPRODUCTION RIGHTS HOLDER:

If the right to grant this reproduction release is held by someone other than the addressee, please provide the appropriate name and address:

Name:

Address:

V. WHERE TO SEND THIS FORM:

Send this form to the following ERIC Clearinghouse:

However, if solicited by the ERIC Facility, or if making an unsolicited

contribution to ERIC, return this form (and the document being contributed)

to:

ERIC Processing and Reference Facility

1100 West Street, 2nd Floor

Laurel, Maryland 20707-3598

Telephone: 301-497-4080

Toll Free: 800-799-3742

FAX: 301-953-0263

e-mail: ericfac@inet.ed.gov

WWW: http://ericfac.piccard.csc.com